Exploring Space on a Small Satellite, STSAT-2 : A Test Bed for New Technologies

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Abstract. The Satellite Technology Research Center (SaTReC) has successfully developed and operated three micro satellites, KITSAT-1, 2, and 3 in the last decade and have developed the flight model of KAISTSAT-4 (STSAT-1) planned for launching in September, 2003. As a successor of the series, the SaTReC is designing the next small satellite STSAT-2 (Science & Technology Satellite-2) which will be launched into a highly eccentric ellipsoidal orbit by the first Korean launch vehicle called KSLV-I (Korean Satellite Launch Vehicle -I) in the end of 2005.

The mission objectives of the STSAT-2 project are to obtain the solar Lyman-alpha image for solar study and to provide the satellite laser ranging for validation of the launch vehicle's performance of inserting a satellite to its desired orbit. Other the main mission objectives, STSAT-2 will perform optimizing the technologies proven throughout the small satellite projects previously developed by the SaTReC, and testing advanced bus technologies for small satellites. To develop and test the innovative technologies, the STSAT-2 spacecraft bus system shall 1) adapt the frame-type structure and electronics boxes, 2) use composite material solar panel, 3) improve the previous start sensors to the dual-head type to achieve higher performance, 4) develop a high-precision CCD digital sun sensor, 5) include a pulsed plasma thruster (PPT) to test the attitude and orbit control, 6) utilize a compact on-board computer (OBC) with a simplified network structure, and finally 7) improve the X-band transmitter to provide up to 10 Mbps data link. Through the above technology developments, STSAT-2 bus system will provide the compact, stable, and optimized bus technologies that can be used for further small satellite missions afterwards.

Introduction

SaTReC has successfully developed and operated three micro satellites, KITSAT-1, KITSAT-2 [1], and KITSAT-3 [2]. All of them are equipped with several payloads to perform experiments in satellite engineering, space science, and earth observation. Since then the small satellite program is renamed as STSAT (Science and Technology Satellite) by Korean government. SaTReC is now finishing the development of STSAT-1 (also known as KAISTSAT-4) [3], a small scientific satellite, based upon the experience and knowledge acquired from the previous missions. STSAT-1 has a main payload called FIMS for astrophysical observation of the diffuse hot plasma in the far ultraviolet range. Also it has other scientific and engineering payload such as SPP (Space Physics Package) and DCS (Data Collection System). The flight model is under acceptance test and waiting for the launch by COSMOS launch vehicle in Russia.

As a successor of STSAT-1, SaTReC has started the next program STSAT-2 [4] which will utilize the first Korean satellite launching vehicle KSLV-1. It will perform the Solar observation and satellite tracking by laser ranging technique. Beside the scientific objectives, STSAT-2 will carry several experimental instruments which will test the advanced bus technologies for small satellites.

In this paper, the previous missions developed by SaTReC are briefly introduced and the design concept of the instruments being developed for STSAT-2 mission is described.

Previous Small Satellite Missions

KITSAT-1 & KITSAT-2 Missions

KITSAT-1, the first Korean Satellite, was developed through the international collaboration with the University of Surrey in the U.K. The next satellite is independently developed with the experience from the collaboration. These two satellites, which are similar in structure and function but different in their orbits, provided a unique opportunity to study the effects of the radiation environment characterized by their orbits.

Both KITSAT-1 and KITSAT-2 carried simple space science experimental instruments to measure the radiation environment around the orbits. Each of them also carried two Earth observation CCD (Charge Coupled Device) cameras, one for wide angle and the other for narrow angle observations. In cooperation with a Korean industrial company, the Samsung Electronics, a color CCD camera was developed and used as the wide angle camera sensor in KISAT-2.

In August 1992, the first Korean Satellite, KITSAT-1 was successfully launched from

Kourou, the French Guiana, by the Ariane 42P rocket as an auxiliary payload to TOPEX/ POSEIDON. Following the successful operation of KITSAT-1, the second Korean satellite, KITSAT-2, was launched at the same site as an auxiliary payload to SPOT-3 in August 1993. Since then, both satellites have produced valuable data for the space science and satellite engineering and images of the Earth's surface.

KITSAT-3 Mission

Following the successful launch and operation of 'technology acquiring satellites', SaTReC developed the next micro satellite in the KITSAT series, KITSAT-3. It was an engineering test satellite launched by the Indian PSLV rocket in May, 1999. Its primary objective is to provide an opportunity to elaborate various technologies for high performance micro satellites and to qualify them in the space environment. As a result of successful launch and operation of KITSAT-3, SaTReC has established an unique and stable bus system which could be adopted to the future missions.

In addition, it has payloads of Multi-spectral Earth Imaging System (MEIS) for the remote sensing and Space Environment Scientific Experiment (SENSE) for space science experiments. For the operation of the remote sensing payload, the sun-synchronous orbit with a fixed local time of descending node near 12:00 and 730 km altitude was selected.

The optical camera in MEIS is a push-broom camera with three linear CCDs. It produces multi spectral images of various terrestrial features in three wave length bands that are similar to those of SPOT. The incoming light is divided by prism and one CCD is assigned to each band. The images acquired from the camera are stored in the solid state recorder that provides the memory capacity of 4 Gbits in total. The solid-state recorder includes flash and SRAM memory blocks developed by Samsung Electronics. The mass memory blocks are manufactured by Samsung Electronics to reduce the physical size using three dimensional packaging.

STSAT-1 (KAISTSAT-4)

The STSAT-1 also known as KAISTSAT-4 is the fourth experimental satellite developed by SaTReC scheduled to be launched in September 2003 by Russian rocket COSMOS. STSAT-1 has a number of missions such as studying space science and exploring advanced space technology with the emphasis on the role of small satellites.

The space science mission is aims at studying the evolution and spatial distribution of hot interstellar medium by performing spectral diagnostics in the Far Ultra Violet (FUV) ranges and investigating the space physics of the Earth's polar region. Korea Astronomy Observatory (KAO) and U.C. Berkeley are involved as cooperating groups to develop the scientific payload called FIMS (Far-ultraviolet IMaging Spectrograph).

STSAT-1 will also deploy a satellite based Data Collection System (DCS) for environment monitoring, wildlife tracking and transportation monitoring purposes. DCS is being jointly developed through an international cooperation with CRCSS (Cooperative Research Center for Satellite System), Australia. KAISTSAT-4 also plans to conduct technology development and verification of a precision star sensor for precise attitude control required for high-resolution earth and space observation.

Mission Objectives of STSAT-2

SaTReC has verified the low cost and small satellites can perform equivalent missions to large and money-consuming program throughout the last decade developing four successful micro satellites ranging from 60 kg to 120 kg. Now STSAT-2 program has started to develop the next science experiment satellite which will be launched to highly eccentric ellipsoidal orbit with the perigee of 300 km and the apogee of 1,500 km by the first Korean launch vehicle scheduled to be launched in the year of 2005.

Throughout evaluation of the proposals from the science societies within Korea, solar observing mission was selected as a main payload and satellite laser ranging (SLR) as a secondary payload.

The main payload of STSAT-2 is named as LIST (Lyman Alpha Imaging Telescope). Hydrogen Lyman-α at 121.6nm is one of the brightest emissions from the chromosphere and transition region of the sun, so it is a natural diagnostic of solar variability in those regions. The main objectives are 1) to understand how the structures in the chromosphere evolves, 2) to improve models of solar VUV (vacuum ultraviolet) irradiance variability by incorporating plage, enhanced network, active network, and quiet Sun indices derived from images of the Sun, and to study the physical properties and processes in the solar active region with Lyman-α images and spectroscopic data.

As mentioned above STSAT-2 will be launched by the firstly developed launch vehicle in Korea. To check the proper insertion to the desired elliptical orbit by the launch vehicle, SLR payload shall measure the precise orbit. Throughout the development and operation, it can also be applied to scientific researches such as atmospheric correction of SLR data, precise ellipsoidal orbit determination, and altimeter/SAR data precision upgrade.

In addition to the science purpose payloads, STSAT-2 will accommodate several advanced bus technologies for small satellites. The key experimental instrument will be described in the later section. Throughout the experiments, STSAT-2 bus system will provide the compact, stable, and optimized bus technologies that can be used for further small satellite missions afterwards.

Spacecraft Design

Overall Design Concept

The STSAT-2 system consists of space segment, ground segment, launch service segment, and various external interfaces including additional ground stations to support image data reception or launch and early operations. The space segment is a satellite consists of the spacecraft bus and payloads. The STSAT-2 ground segment consists of the ground station at SaTReC site. Figure 1 shows the architecture of the STSAT-2 system.

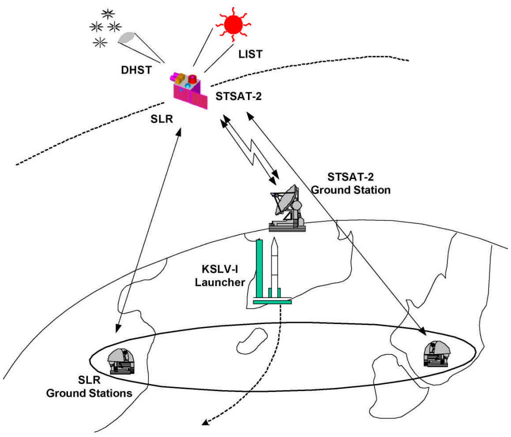

Figure 1. STSAT-2 System Architecture

Since the launch vehicle itself is experimental, the mass and volume constraints are very strict. We have adapted frame-type structure for efficient use of the internal space within the mass and volume constraints. By using a high speed CPU in OBC (On Board Computer) module [5], communication between subsystems could be realized without internal network controller and by using FPGA's instead of logic IC's, more compact spacecraft bus system is designed. The general specifications of STSAT-2 are listed in table 1.

The electrical configuration of the satellite system is also depicted in figure 2. The bus electrical system consists of CDS (Command and Data handling Subsystem), EPS (Electrical Power Subsystem), ACS (Attitude Control Subsystem), and CMS (Communication Subsystem). Each subsystem is designed to satisfy the mission requirement from the payloads and technology experimental instruments.

The constituent and function of each subsystem is described in the following sections.

Table 1. STSAT-2 Satellite Specifications

Item	Specifications
Mass	< 100 Kg
Volume	< Φ1m × 1m
Structure	Hexagonal Frame Type
Power	Input power : 165 W @ BOL 7Ah Capacity Battery
Attitude Control	Pointing Accuracy < 0.15 ° Stability : 0.002 ° 3σ in LIST exposure time
RF Transmission	X-band Data Download ~ 10 Mbps S-band Uplink and Downlink Uplink : 1200/9600 bps Downlink : 9600/38400 bps
Satellite Control	Centralized Control CPU : 603e

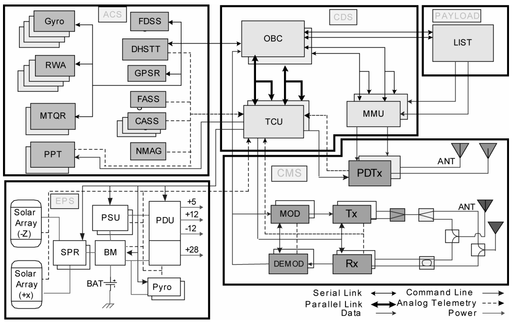

Figure 2. STSAT-2 Electrical Configuration

Payloads

LIST is the main payload of STSAT-2 which will observe the Lyman image of the solar full disk. Optical design configuration of the payload is shown in figure 3. The optics system is configured to have a Ritchey-Chrétien telescope with an effective focal length of 940 mm. At the focal plane, an ultraviolet-sensitive CCD with 1024 $\times$ 1024 pixel is located to get the image of solar disk. To fully take the solar disk in a frame, the effective focal length and the image area of 13.3 $\times$ 13.3 mm^2 are adjusted to each other.

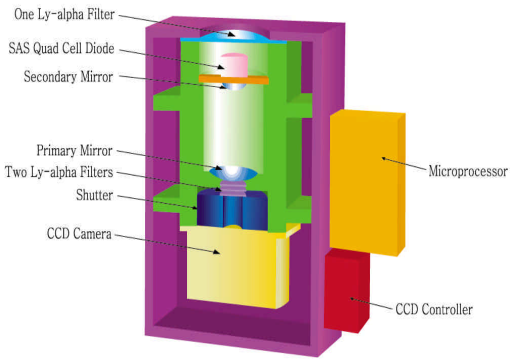

Figure 3. LIST Optics Configuration

The CCD is sensitive to photons ranging from 10 nm to 1000 nm. To reduce the light from different wavelength, three Lyman-α filters of 10 nm FWHM band pass are used so the intensity of photons from unwanted wavelength is reduced less than 2 %. The solar image will be taken ~16 frames per orbit, and the data are transferred to MMU (Mass Memory Unit) frame by frame and then downloaded to ground via high speed X-band transmission. The transmission speed will be upgraded from 3 Mbps to 10 Mbps to compensate limited contact time result from high eccentric ellipsoidal orbit.

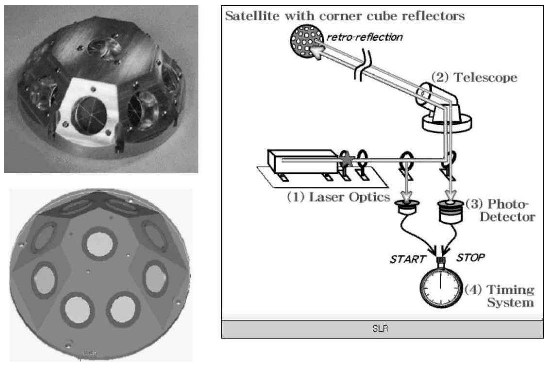

Figure 4. SLR Reflector Array and Principle of Satellite Ranging Measurement

As a secondary payload, SLR (Satellite Laser Ranging) experiment is under development. As depicted in figure 4. SLR is an array of retro-reflectors which reflect laser beam from laser ranging ground station to the retro direction. By measuring the time difference between the starting and arriving laser pulse, the distance to the array can be exactly measured with a precision of a few cm according to the errors in the used laser and time measuring electronics.

Power

Array of GaAs solar cell will be used as a power source and NiCd battery stores the energy for operation during eclipses. From rigorous power budget analysis, 165W@BOL be generated from solar cell and 7Ah with +28V capacity battery cell will guarantee 25% DOD (Depth of Discharge). Single point ground scheme is accepted and payloads and payload data transmission module will be separated from the bus ground point to protect the noise sensitive electronics.

The satellite is initialized by a mechanical separation switch attached to launch vehicle adaptor. Firstly, the solar panels are folded to the satellite body because of the dimensional and dynamic environmental constraints. After the separation with the launch vehicle, pyro devices ignite the unfolding mechanism so that the solar panels supply sufficient power for the mission execution.

Command and Telemetry Control

Command and telemetry of STSAT-2 are controlled by OBC (On Board Computer) and TCU (Telemetry and Command Unit). To select CPU for OBC module, we have surveyed various CPU's available within the budget considering radiation tolerance, package type, floating point processing, real time operation system, prospect for reuse etc. We have selected PowerPC 603e as the CPU of OBC.

PowerPC 603e has a high spped computing capacity upto 423 MIPS (mega instruction per second) with low power consumption less than 4 Watts. Considered in the environmental point of view, 603e is supplied in military grade so it is somewhat tolerant to radiation and thermal environment which is suitable for small satellite in high eccentric ellipsoidal orbit where the space environment changes quickly. As an operating system of the OBC, VxWorks was adopted considering the stability and reliability proven throughout various space missions such as PROBA and Pathfinder etc.

Electrical configuration of the OBC is depicted in figure 5. To overcome the errors that occur by single event phenomena, Reed-Solomon error detection and correction scheme will be implanted. For ground contact two USART link will be used and ~20 UART will communicate with attitude sensors, controllers and payloads.

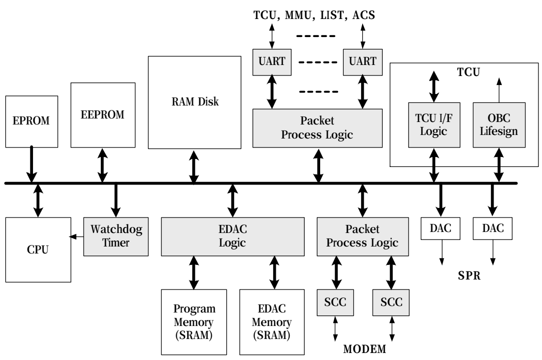

Figure 5. STSAT-2 OBC Configuration

Telemetry are sampled by TCU module and stored in RAM disk. And a packet processing logic embodied with FPGA's will deliver valid packets from other modules to the OBC for efficient interrupt routine execution.

Attitude Control

To carry out the solar observation stably, STSAT-2 accepts 3 axis attitude control system. The attitude sensor of STSAT-2 consists of coarse and fine analog sun sensors, a fine digital sun sensor, a star tracker and a magnetometer. Fiber optic gyros will serve as a rotation sensor, reaction wheel array is dedicated to control the attitude accurately while a magneto torque bar dump the bias momentum. And orbit parameters are updated via ground contact or onboard by GPS receiver.

Once the attitude information are collected in OBC by serial communication or telemetry sampling as depicted in figure 2, the OBC shall perform the attitude determination and control as a multitasking onboard process.

Structure

The hexagonal structure with 3 unfolding solar panels is selected based on comparison between several candidates in terms of structural analysis, efficiency of integration, harness routing, compactness etc. The arrangement and specific dimensioning is under study based on detailed mission analysis and subsystem requirements as depicted in figure 6.

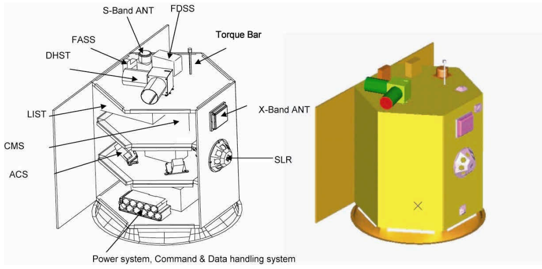

Figure 6. STSAT-2 Structure (Candidate)

RF Communication

The RF communications subsystem of STSAT-2 consists of telemetry and telecommand transmitter unit and payload data transmitter unit. Telemetry and tele command are transmitted in S-band RF frequency. Tele commands are transmitted with 9600 or 1200 bps and telemetry information are downloaded with 9600 or 38.4 kbps [6].

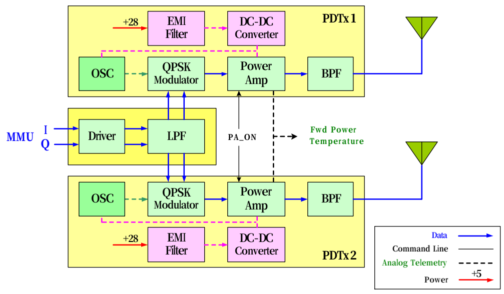

Figure 7. X-band PDTx Configuration

According to preliminary orbit analyses, the ground contact time and the distance to the satellite varies since the orbit is elliptical and not sun-synchronous. So within the contact time when the download link margin is larger than 3dB with a BER (bit error rate) of 10^{-6}, all the stored image data should be downloaded. Mass memory unit stores about 200 frames per day, total amount of 4 Gigabits. Orbit analysis says that the satellite can contact at least 2 times with 5 min. each in average implying that the transmission speed should be larger than 7 Mbps. We are designing the X-band transmitter with 10 Mbps and QPSK modulation scheme as shown in figure 7.

Satellite Technology Experiments

As mentioned above, several satellite technology will be explored on STSAT-2. In this section, three representative experimental instruments will be introduced.

Dual Head Star Tracker

Among the four satellites we have developed so far, last two have star trackers for attitude sensing. All of them have single head optics so the accuracy in optical axis of the star tracker is naturally lower than other two axes. This can be easily understood since the accuracy in the optical axis is inversely proportional to the distance from the imaging center while those in the other axes are inversely proportional to the focal length.

To overcome this inconsistency, DHST (dual head start tracker) which has two optics assembly whose optical axes aligned in different direction sharing the same image processing and readout electronics is under study [7]. If the angle approaches 90°, the attitude accuracy in the optical axis will have similar value with the other axes, nominally 10 arc seconds for STSAT-2. In addition, dual head star tracker can increase the probability of star image acquisition if there are obstacles in the field of view such as the Sun, the Earth, and the Moon.

Pulsed Plasma Thruster

An electrical propulsion system will be equipped and tested in STSAT-2. PPT (Pulsed Plasma Thruster) gets propulsion by sublimating Teflon at high voltage. PPT has simple structure without any valve or tank and very high specific impulse. When the electrical energy stored in a capacity bank is released, a voltage of 1.5 keV is imposed in a spark plug. Impulse bit and specific impulse are 20 μNs and 700 s respectively and will be operated with a frequency of ~ 10 Hz [8].

Fine Digital Sun Sensor

With the development of electrical image sensors, digital sun sensors without any optical lens are showing that a precision of 0.01 °can be reached. In STSAT-2, a fine digital sun sensor with a CMOS CCD with 120 deg FOV and 0.025 deg (2 axes, 3 σ) accuracy will be installed. A laser thrilled hole of about 200 μm in a thin (order of 100 μm) metal sheet in front of a CCD acts as an optical element. A micro controller generates signals to operate CCD, acquires image, calculates center of the intensity, and then reports the attitude information to OBC via serial communication.

Summary

We have briefly introduced the missions that SaTReC has developed and operated successfully.

Now we are developing the next satellite named as STSAT-2 that will be launched in the year of 2005 by the first Korean satellite launce vehicle in Naru space center located in the southern coast of Korean peninsular.

The mission objectives are to observe the solar activities in far ultra violet range especially in Lyman alpha line emission and to provide exact orbit measurement by satellite laser ranging technology. The conceptual design of STSAT-2 is described and technology experiment items are also introduced. With the development of STSAT-2 bus system, SaTReC will provide the compact, stable, and optimized bus technologies that can be used for further small satellite missions afterwards.

Acknowledgements

This work has been conducted in support of STSAT-2 program funded by Korean Ministry of Science and Technology. The authors would like to thank the team at SaTReC involved in STSAT-2 program for their hardworking.

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